Intuitive operation and pilot training when using marine azimuthing control devices

AZIPILOT

Report Title: Deliverable 4.10: Map out the landscape of future R&D

Contents

PUBLISHABLE EXECUTIVE SUMMARY

WP 4 Operational Practice is aimed at collating, reviewing and auditing available material that is relative to the operation of azimuthing control devices when manoeuvring ships in Pilotage waters.

Task 4.10 reviews the work undertaken in Tasks 4.2 *Review of existing operational practice*, Task 4.3 *Review of Accident and Incident Reports* Task 4.4 *Review of Bridge Operational Practice and the Human Interface*, Task 4.5 *Encapsulate knowledge using integration and Evaluation Exercises*, Task 4.6 *Summarise Current operational Practice and limitations,* Task 4.7 *Assimilate Cross Disciplinary knowledge from other WPs,* Task 4.8 *Recommendations to improve current operational practice* should be read in conjunction with Task 3.9 *Integrate knowledge by recommending training programmes* and Task 4.9 *Recommendations for specific regulations and criteria.*

From the review this Task has identified areas in which future research and development would be beneficial to Ships Officers and Marine Pilots of vessels fitted with azimuthing control devices. Manufacturers of bridge equipment, both hardware and soft ware, should be encouraged to standardise both control handles and modes of operation to avoid confusion among ships officers and Pilots. All controllers should be fully synchronised to assist and simplify the transfer of control between consoles during the manoeuvring phase of the voyage. From the work to date across the whole Project it is recommended that the training courses currently on offer should be further developed to include more technical theory on the operation of ACD's. From this improved technical theory students will have a more comprehensive understanding and better insight into how the ACD's should be operated to obtain maximum efficiency, minimise mechanical failures and thereby prolong the working life of the units.

Task 3.9 examined in detail the current regulations contained within IMO STCW and makes comprehensive recommendations for improving on the current position ultimately leading to the development of an IMO Model Course for Basic shiphandling and advanced ACD ship handling. There is a need for further research into the procedure to follow to execute an emergency stop. Such research should be aimed at obtaining accurate data, both from manned models and mathematical models, from which further development in the use of an emergency stop procedure can take place. Such further research should also explore more fully the mechanical stresses placed on the units and ships structure when undertaking such a manoeuvre. The results so obtained could then be programmed into the ships software so that once the emergency stop is ordered the units will respond automatically to the programmed software.

There are numerous different types of ACD units available at present and many have different freedoms that will obviously produce many different results in terms of efficiency and operation. This would suggest that there is room for further testing on scale models to help understanding and development of future systems.

1. INTRODUCTION

This task will look at the conclusions and recommendations made in the previous tasks within Work Package 4 and from the results obtained and observations made will identify areas in which future research and development could be undertaken that would be beneficial to Ships Officers and Maritime Pilots of vessels fitted with azimuthing control devices.

2. REVIEW OF EXISTING OPERATIONAL PRACTICE

Task 4.2 set out to establish the extent and content of existing operational practice and guidance issued by ship owners, equipment manufacturers, Pilotage Organisations to Ships Officers and Maritime Pilots. This was achieved through interviews with Ships Officers working onboard Azimuthing Control Devices (ACD's) equipped vessels and through a worldwide survey of Pilot Organisations and Pilotage Authorities responsible for providing pilotage services.

Task 4.2 concluded that there is a need to increase the understanding of both the ship owners/operators and Pilot Organisations/ Authorities towards providing suitable training to Ships Officers and Maritime Pilots operating onboard ACD equipped vessels.

3. REVIEW OF ACCIDENT AND INCIDENT REPORTS

Task 4.3 undertook a review of accident and incident reports that involved ACD propelled vessels.

The above summary shows that while no one fault exists in all the incidents there is some commonalty in that manoeuvring error and transfer of control issues are relevant in 60% of the incidents. In the incidents highlighting manoeuvring error as a factor the reports recommend further training and familiarization as being necessary despite the individuals having considerable experience at sea this has not always been onboard the vessels involved in the incident. In the incidents highlighting transfer of control issues the reports recommend improved onboard procedures and an improvement in equipment knowledge for the ships officers.

The number of incidents investigated is minor when compared to the total number of Very Serious and Serious Incidents available for inspection. It was expected that more incidents would have occurred due to an expected lack of appreciation by personnel of the special characteristics of azimuthing propulsion and inadequate onboard procedures.

Task 4.3 concluded that further training and familiarisation was necessary and that there should be an improvement in onboard procedures and an improvement in equipment knowledge for ships officers

4. REVIEW OF BRIDGE OPERATIONAL PRACTICE AND THE HUMAN INTERFACE

Task 4.4 the task was focused on a review of bridge operational practice and human interface, in particular it addressed ships using ACD's. The main objectives were to promote understanding of the needs of the bridge crews and ensure that this information is passed back to the bridge and systems design engineers, with the scope of enhancing usability and efficiency of these systems.

Task 4.4 concluded that hardware (control handles) should be configured so that they can only be turned at the same rate as the pods can be moved. This is an approach that perhaps would be problematic for the operator who is use to having a delay between giving an order and that order taking effect and such configuration would be of no value to the operator. Bridge consoles could be equipped with an alarm system (visual or acoustic) so that the operator could be supported during manoeuvres, being continuously aware of the situation and warned in time if something is going wrong. There should be an agreement among all manufacturers of ACDs with a view to standardise their equipment in terms of tools available, labels, wording used, etc. In that way, operators could be familiar to the systems whatever ship they sail and risks of errors connected to misunderstanding could drastically be reduced.

5. ENCAPSULATE KNOWLEDGE USING INTEGRATION AND EVALUATION EXERCISES

Task 4.5 summarised knowledge gathered in other tasks into an accessible form and in doing so proposes practical solutions for handling ACD propelled vessels. Typical manoeuvres were undertaken both in normal and emergency scenario's with a podded manned model. For turning circles the effect of twin pods on the turning diameter is similar to that of a rudder with twice the angle. In the situation of experiencing a pod failure the turning diameter is less affected when the inboard pod is still functional.

With regard to crash stops there are several suggested methods of quickly bringing the vessel to a stop. In Task report 4.6 the manufacturer, ABB, suggest in their Operating Instructions that the most effective way to perform a crash stop is 'The Pod Way'. This manoeuvre requires the pods to be turned through 180º outboard thereby maintaining positive thrust throughout. The Operating Guidelines suggest the pods be turned outboard but states it is not forbidden to turn the pods inboard. (turning pods outboard is defined by ABB as 'turning the propeller end outboards') NB note this definition only works for 'pulling pods'. Trials during 4.5 at Port Revel indicated that the shortest stopping distance was achieved turning the pods inboard and that by turning them inwards is slightly less efficient.

During interviews with ships staff experienced in ACD operations 'The Pod Way' as described by ABB, turning pods outboard is the preferred method. When operating the 'Aziman' mode to desynchronise the pods, this action also activates the control programme for the propeller revolutions. Revolutions are automatically decreased as the pods reach 90 degrees and as the pods turn through to 180º the power is increased to full. The decrease in revolutions helps reduce stresses on the pods during the rotation.

An alternative crash stop method is to turn the pods inboard 90º and use the transverse arrest method to slow the vessel down. This method not only has the water directed outboard acting as braking force but is also supplemented by the drag effect of the pod unit(s) themselves.

From the above it is clear that further trials and testing using both physical and mathematical models are required to evaluate further the above methods and obtain more data, so that can be included in future training programmes. In the course of such trials the stresses placed upon the units and ships structure during this manoeuvre should be explored.

6. SUMMARISE CURRENT OPERATIONAL PRACTICE AND LIMITATIONS

Task 4.6 summarised operational best practice while highlighting the limitation for pilots and ships officers when operating ships equipped with Azimuthing Control Devices (ACD's). The use of ACD's provides the ship handler with an infinite number of solutions, which in itself introduces potential problems that may be detrimental to both the success of the intended manoeuvre and to the preservation and protection of the azimuthing device itself as well as to the Port infrastructure.

Task 4.6 concluded that while it can be appreciated that due to the increased flexibility provided by ACD and the infinite number of responses and actions open to the ship handler, it could be forgiven for reaching the conclusion that little or no training would be required. This would be to seriously underestimate the counter intuitive nature and complexity of this method of manoeuvring and the potential consequences for a ship owner/operator, should inappropriate operational practices result in premature bearing failure or damage to the ship and/or to the Port infrastructure. It is therefore important to identify the most suitable ship handling procedures to validate operational best practice and also examine the limitations of each manoeuvre.

Authorities responsible for the provision of Pilotage services and Ship owners/operators should ensure that personnel operating ACD units receive a through and comprehensive understanding of the theory behind the operation of such units and be trained in their efficient and effective use to ensure the safety and security of life and property. This should be supported by regulation, especially in STCW.

7. FUTURE RESEARCH AND DEVELOPMENT

The tasks performed as part of Work Package 4 strongly suggest that there is still further work to be done, through research and development to improve the operational practice for vessels equipped with ACD's.

7.1 Bridge Hardware Development

Manufacturers of bridge equipment, both hardware and software, should be encouraged to standardise both control handles and modes of operation to avoid confusion and errors among ships officers and pilots. All controllers should be fully synchronized to assist and simplify the transfer of control between consoles during the manoeuvring phase of the voyage. Future development of control handles should consider either an automatic system that prevents large volumes of water being directed onto another pod as standard and/or the inclusion of an alarm system to indicate to the operator when an ACD is not being operated in the most appropriate manner. During the course of the project the use of automatic systems were identified as being used by one ship operator/owner but this was the exception rather than the norm. With regard to the incorporation of an alarm system such warnings are commonly used through the use of haptic controls in aircraft cockpit instrumentation to alert the pilot to a stalling situation and this technology could be extended to the maritime sector. It is often suggested by equipment manufacturers that standardisation leads to a stagnation in development but again drawing comparisons with the developments in aircraft cockpit control and monitoring devices this suggestion cannot be substantiated.

7.2 Training Programmes

During the course of the Project it has proved difficult to obtain information issued to ships officers and Pilots from manufacturers and ship owners/operators. One operator had issued comprehensive guidance but the work of the project came to the conclusion that in some areas this guidance was in fact not very practical to apply.

The Project has looked at the various training programmes offered by both Manned Model Centres and Bridge Simulator Facilities. Students attending such courses have reported that they have all offered invaluable training into the operation of ACD's while at the same time improving operator confidence. WP 3 has comprehensively examined the current training available, whilst WP 4 has examined the current operational practice onboard ACD vessels.

From the work to date across the whole Project it is recommended that the training courses currently on offer should be further developed to include more technical theory on the operation of ACD's. From this improved technical theory students will have a more comprehensive understanding and better insight into how the ACD's should be operated to obtain maximum efficiency, minimise mechanical failures and thereby prolong the working life of the units. Once developed and agreed between the various training facilities the existence of such a course should then be brought to the attention of Pilot Organisations, Ship Owner Representatives and Maritime Training Facilities.

The contents and structure of training courses currently on offer should be reviewed with the objective to gradually introduce the student into the complexities of the operation of such ACD units and gradually introduce in small increments more complex manoeuvres, as the training course progresses. For Pilots in particular the requirement to begin training on such units at a basic level is particularly necessary as the evidence from task 4.2 indicates that they are unlikely to have undergone any basic training with ACD's.

The use of a standard verbal terminology, as suggested by Baken & Berkley in 2008, could be incorporated into the IMO Standard Marine Navigation Vocabulary (SNMV), which was updated by Standard Marine Communication Phrases (SMCP) and adopted in 2001. The use of such phrases, overcomes the problem of language barriers at sea and avoid misunderstandings which can cause accidents. While the operation of ACD units lends itself to on hands operation by the Master or Pilot during the course of the Project it was discovered that as a result of poor equipment layout and/or failure not all vessels were manoeuvred from the bridge wing control console position. This led to the use of verbal orders being issued by the Master/Pilot to the operator at the central console. Such a verbal order could be issued in the following manner:

Pod/Direction/Thrust/Power

A typical order would thus be:

Port pod, inboard 30º, positive thrust, 35 rpm.

However, this depends on international definitions of what, for example, 'inboard 30º' or 'positive thrust' means, also the result for pulling pods, may well be different for pushing pods. Other tasks within the project have highlighted the many different types of ACD's are available and as such the use of a standard verbal terminology that would be applicable to all unit types and methods of operation would be difficult to achieve.

However the existence of such terminology should be acknowledged. Hence, a language that is 'result orientated' may achieve better universal results.

During one ship visit it was noted that the Master gave orders by the use of negative and positive numbers in recognition of negative and positive thrust, whilst maintaining both controls in a 'fixed' T bone position. In this instance the units were set at the desired angle and this angle was maintained throughout the manoeuvre, thereby not taking full potential of the azimuthing capability and also produced situations when water was being sent onto the adjacent unit and the fin keel thereby increasing the risk of equipment damage and uncertainty of exactly where the thrust was going. During this visit and observation (which was recorded on video) of this manoeuvre, it was noted that the operator of the controls at one point became confused and in fact placed the thrust levels at something different to that ordered (negative thrust, when positive thrust was clearly ordered), fortunately without any untoward consequences on this occasion. This highlights that verbal commands with multiple units can easily lead to confusion and errors.

In another case, the Master was operating the Bow Thrust from the bridge wing control, and giving verbal orders in Russian to the Mate who was operating the azimuthing controls from the centre console and not at all times to orders from the Master. Needless to say the 'command and control' of this vessel was far from ideal, as the vessel was also subject to compulsory pilotage at the time and the Pilot was having difficulty to comprehend what was going on. It is also understood that SMNV's and SMCP's are not popular at IMO are therefore we conclude that a more practical solution to the problem of verbal commands, should they be necessary at all, on such versatile equipment, may be the use of 'result orientated' commands.

However, generally the control of ACD's tends to be a tactile 'hands on' practice and giving verbal commands in a multi unit system would be prone to errors, especially in the translation and a maybe a rather rigid method of using this type of versatile propulsion control. However, it is recognised that any 'hands on' approach does have a tendency for a single point error, that may not be picked up by other members of a 'bridge team' and we would recommend this an area of further research. A pilot of an aircraft has always operated with a 'hands on' approach and has never used verbal commands but is supported by strong procedures and often a co-pilot. We have also noted that the above terminology when applied to Azipods (pulling pods), if also applied to pushing pods, has quite different results. Hence, pilots in particular, could be confused by this, if they fail to comprehend (or it is not explained) whether a pod is pulling or pushing. We therefore recommend that further work is required and suggest that 'result orientated' commands (if verbal commands are used at all) may well be a better approach.

7.3 Emergency Stop

As previously mentioned above during the course of the Project it has proved difficult to obtain information issued to ships officers/pilots from both equipment manufacturers and ship operators on how ACD's are best operated. With regard to the procedure to follow to execute an emergency stop, information obtained from a manufacturer suggests rotating the units through 180º thereby maintaining positive thrust at all times. During the review phase of the project this approach was supported by an experienced ship master who reported that during sea trials of a large cruise liner, the use of this manoeuvre brought the vessel to a stop in three ship lengths from an initial speed of 15 knots whilst maintaining the ships heading. This emergency stop procedure is to be distinguished from a controlled slow down at the end of the Cruise Mode period and prior to entering the Manoeuvring Mode. During this controlled slow down the vessels speed is slowly reduced by a gradual decrease in revolutions while maintaining the planned course as the vessel approaches the Port Limits.

There is another recognised way of bringing a vessel to a stop quickly and that is through the use of the transverse arrest. The units are operated through 90º so the water is directed away from the vessel. This 'wall' of water at 90º to the direction of travel creates a breaking force, which is further supplemented by the drag effect of the units themselves. There is a need for further research into the above methods to obtain accurate data, from which further development in the use of an emergency stop procedure can take place. The results so obtained could then be programmed into the ships software, so that once the emergency stop is ordered the units will respond automatically to the programmed software.

7.4 Configurations of Units

Task 4.6 summarised the current operational practice and limitations of ACD units that are currently available on the open market. The many different types available at present have many different freedoms that will obviously produce many different results in terms of efficiency and operation. This would suggest that there is room for further testing on scale models to help understanding and development of future systems.

8. Improvements in Current Operational Practice

Task 4.8 examined current onboard operational practices and ship designs specifically of ACD vessels and made recommendations for improvements.

A clear majority of Pilots and ship masters have expressed an opinion that there is the need for specific training courses for ships equipped with Azimuthing Control Devices (ACD's), in particular to enhance knowledge and skill in handling ships in a safe and intuitive manner with Azimuthing propulsion devices in varying critical situations. This is necessary in order to improve safety at sea, especially when berthing or unberthing.

However, whilst Ship Handlers, both Masters and Pilots, overwhelmingly want to be trained to use ACD's and that STCW requires them to be trained, depending on one's interpretation of the Code. Despite this Ship's Officers, Masters and Pilots who operate ACD's have not received training in the use of ACD's. Does this imply that there is something wrong with current regulation, as there appears to be a mismatch between what is expected and what in happening in reality. There are some recommendations to improve safe operational practice:

- Standardisation of ACD design and terminology (either across a fleet or better still across the whole industry)
- Synchronisation of ACD's in the different manoeuvring positions which simplifies procedures for changing control
- Design of Haptic feed-back systems informing the user of the status of the system
- Develop and practise on board procedures

- Be practised in using equipment when a unit fails
- Be familiar with emergency scenarios and procedures
- Promulgate manufacturers recommendations/limitations of equipment
- Mandatory training in ACD ship handling for watch keeping officers, masters and pilots.

Task 4.8 also offers a discussion of the general engineering implications when selecting ACD's, and more specifically, azimuthing pod-drives with the aim of providing the practicing naval architect with a background to the technology and general guidance for its application. The potential benefits of ACD's have proved very attractive to ship operators who, in turn, have demanded more and better from the pod manufactures. This forced evolution has placed significant demand on the pod manufactures to respond, authorities to legislate and on the crews of pod- driven ships to learn how to best operate these new technologies.

The modifications in the stern-form can offer better use of space for car decks and the manoeuvring performance is quite suitable for the typical mission profile of Ro-Ro and Ropax applications. Also, while the good manoeuvring performance is most attractive for missions with substantial harbour operating time, the pod solution is shown to be equally applicable for long haul routes; including fast ship applications. Pods can offer advantages for high-speed applications but careful attention must be given to find the optimal balance between motor-size and hydrodynamic efficiency as well as to cavitation performance.

The main advantages offered when using pods is the improved manoeuvrability and propulsive performance. However, it is also shown that pods experience significant spike loads that are in origin related to dynamic manoeuvring. Consequently, it is recommended that the preliminary design be as course-stable as possible; reducing acceleration dependant loading and assuring good course- keeping behaviour.

For the pod structure and more specifically the bearings, it is important to consider the gyroscopic precession loading. For the structural analysis, stress concentrations factor methods are found to provide unreliable results due to complicated loading patterns and three-dimensional effects. Consequently, a finite-element analysis using a global-local technique is recommended.

One final qualitative advantage of the pod solution is identified as the greater flexibility with the general arrangements. This can have significant impact on both the space arrangements and the redundancy capacity of the ship. With the application to a wider range of ship-types and with increasingly innovative designs, it is certain that we will see many new varieties of efficient and profitable pod-driven ships in the coming years.

9. Recommendations for Training Programmes

The objective of Task 3.9, which should be read in conjunction with Task 4.8, is to compile the main project outcomes into a form that is readily exploitable for use in Maritime Pilot training and the wider maritime industry. Specifically, the STCW95 (Standards for Training, Certification and Watch-keeping) Code regulates the required competences for all ships operators. According to the STCW95 code, ship masters and chief officers functioning at management level onboard ships more than 500 GT shall possess very specific competences including 'be able to respond to navigational emergencies' and 'manoeuvre and handle a ship in all conditions'.

In theory, everyone with a STCW95 certificate should have met these shiphandling requirements. Experience shows that whilst some shipping companies have met and followed this standard, sadly many have not. Asking why is beyond the scope of this report, but it is a very interesting question nevertheless. Our studies within the project indicate that training for ACD's is necessary and operators are keen to embrace such training. However, before specialist ACD's training can be specified, we have to assume a basic level of competence in shiphandling first. Hence, candidates should have attended a basic shiphandling course prior to embarking on a specialist ACD course. There is nothing in the Code that is specific to training on ACD's. However, some parts could be interpreted as such. This is unsatisfactory, as experience has shown that the 'good operators' do take up appropriate training, whilst many do not. It is recommended that a specific specialist training regime should be added to the Code for ACD vessels.

Pilots are not covered by STCW95 although Resolution 10 invites IMO to consider developing provisions covering the training and certification of Maritime Pilots, through which **IMO Resolution A960 (23)** (Recommendations on training and certification and operational procedures for Maritime Pilots other than Deep-Sea Pilots) has been developed in 2004.

European Training and Certification Standards, ETCS, was developed in 2005 by the European Maritime Pilots' Association as a template for training Maritime Pilots and some European countries have or are currently in the process of embracing these standards. Pilotage is a port state control activity that takes place in territorial waters and is inherently local in nature and therefore difficult, if not impossible, to apply to an International Standard. There are numerous national and international codes and recommendations but little, if anything, is mandatory. STCW95 resolution 10 invites IMO to consider developing provisions covering the training and certification of Maritime Pilots and we would commend ETCS as an appropriate template to take this forward to be developed, whereby provision for specialist ACD training for Pilots could be made.

10. Conclusion

WP 4 has examined many aspects of the Operational Practice currently engaged by Mariners working onboard vessels propelled by ACD's. During this examination it has become apparent that there is still a number of unanswered questions and further work to be undertaken to ensure that procedures are in place and comprehensive training programmes developed and made available to ship owners/operators and Pilotage Authorities responsible for the training of pilots. Manufacturers of bridge equipment, both hardware and software, should be encouraged to standardise both control handles and modes of operation to avoid confusion among ships officers and in particular Pilots. From the work to date across the whole Project it is recommended that the training courses currently on offer should be further developed to include more technical theory on the operation of ACD's. We also recommend that STCW is developed to make training on ACD's mandatory and to that end, that a IMO Model Course is also developed.

- The IMO STCW (Annex Chapter II) Table A-II/2 (page 42) – is amended to reflect a specific mandatory requirement for specialist training with ACD's and any other unusual or extraordinary manoeuvring/propulsion devices.

- The IMO STCW (Annex Chapter II) Table A-II/2 column 3 (page 48) ***'Methods for demonstrating competence'*** that 'Examination and assessment of evidence obtained' from '***Approved in-service experience'*** is removed.

- The IMO STCW Annex Chapter 5 Section B-V/a (Page 255) is amended accordingly to specifically detail ACD vessels.

- The IMO Resolution A960 (23) Annex 1 - 5.5 is amended with a paragraph detailing 'knowledge of and specialist training in the manoeuvring of ACD's or other unusual or extraordinary manoeuvring/propulsion devices'.

- STCW95 Resolution 10 invites IMO to consider developing provisions covering the training and certification of Maritime Pilots, from which A960 (23) has been developed and we recommend that this should be amended to encompass training in ACD's for pilots. (ETCS (Education, Training and Certification Standards) has already been developed in Europe and this would provide a suitable model for the certification and training of Maritime Pilots inclusive of provisions for ACD's)

- IMO Model Course 7.01 (1.9 Manoeuvre and Handle the Ship in all Conditions) needs urgent updating to include Full Mission Bridge Simulators (FMBS) and Manned Model Simulators (MMS) as methods of determining competency in Ship-handling. There is a need for further research to obtain accurate data from which further development in the use of an emergency stop procedure can take place.

Further work is necessary to discover a more practical solution to the problem of verbal commands, should they be necessary, on such versatile and tactile equipment. We would recommend a 'result orientated' approach due to the variety of ACD's encountered (pulling/pushing).

The many different types of units available at present that have many different freedoms. This would suggest that there is room for further testing on scale models to help understanding and development of future systems. A clear majority of Pilots and ship masters have expressed an opinion that there is the need for specific training courses for ships equipped with ACD’s, in particular to enhance knowledge and skill in handling ships in a safe and intuitive manner with Azimuthing propulsion devices in varying critical situations. This is necessary in order to improve safety at sea, especially when berthing or unberthing.

The main advantages offered when using pods is the improved manoeuvrability and propulsive performance. However, it is also shown that pods experience significant spike loads that are in origin related to dynamic manoeuvring. Consequently, it is recommended that the preliminary design be as course-stable as possible; reducing acceleration dependant loading and assuring good course-keeping behaviour. For the pod structure and more specifically the bearings, it is important to consider the gyroscopic precession loading. For the structural analysis, stress concentrations factor methods are found to provide unreliable results due to complicated loading patterns and three-dimensional effects. Consequently, a finite-element analysis using a global-local technique is recommended.